Approaches for Developing Uniform Hazard Spectra at Critical Facilities

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Seismic Lessons Learned Panel Meeting

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Discussion Topics

- Definitions of different approaches for developing soil UHS that are consistent with rock UHS
  - Approaches 1, 2A, 2B, 3, and 4
- ASCE 4/43 requirements have recently been modified to emphasize Approach 3
- Example of Approach 1/2A calibrated to Approach 3 at LANL

Why Evaluation is Needed

- PSHA is often defined at a rock interface; need to develop consistent PSHA definition at facility foundation level
- For embedded facilities, may also need to develop hazard-consistent motions at several elevations within the soil profile
- PSHA may not be able to be repeated
  - Too costly
  - Attenuation models of the soil site may not be available

NUREG/CR-6728-Table 6-1

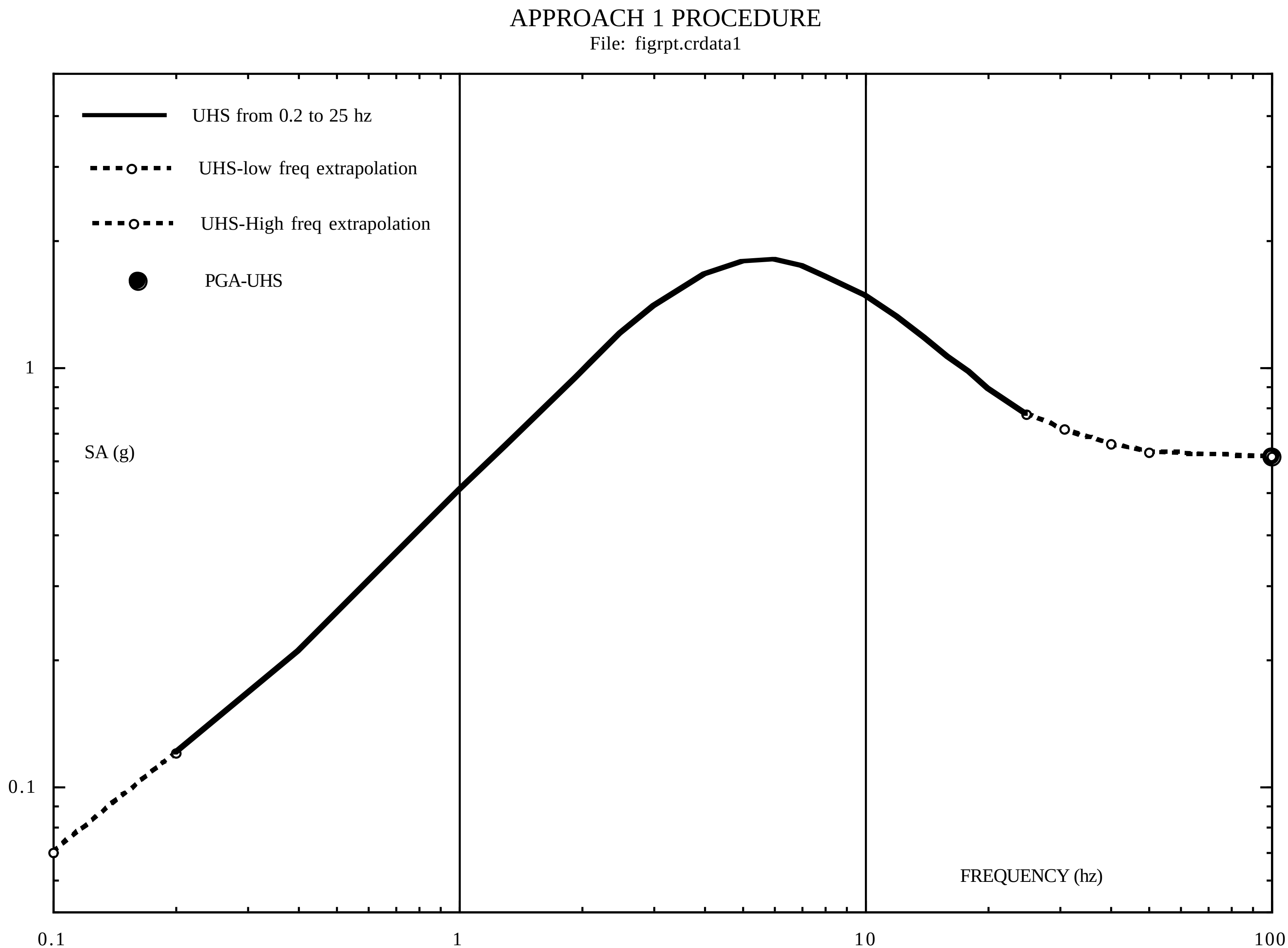
Overview of Approaches for Developing Soil UHS

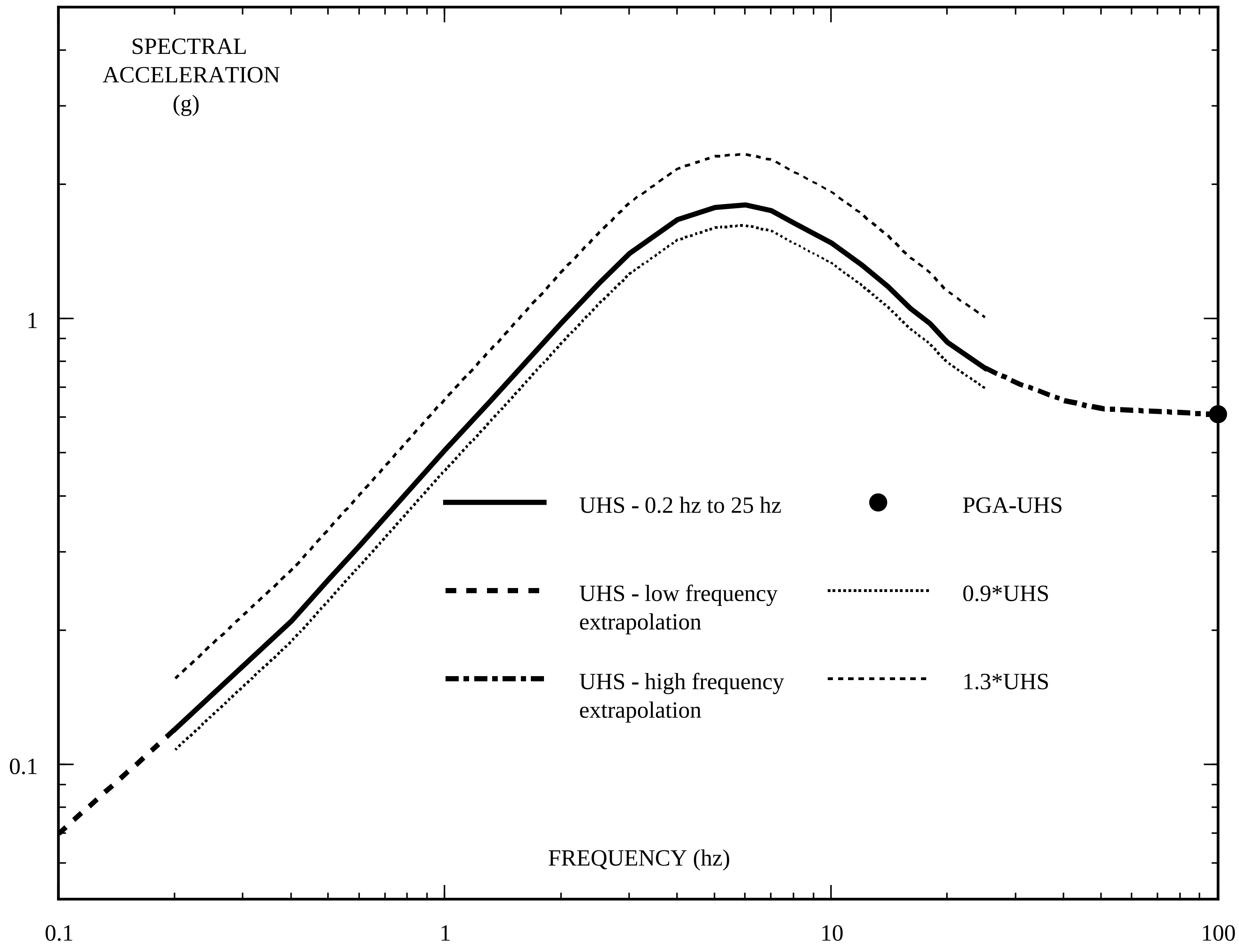
- Approach 1: Rock UHS used as control motions to drive soil column.
- Approach 2A: Use scaled 1 Hz and 10 Hz design earthquakes as control motions to develop 1 Hz and 10 Hz soil motions (R.G. 1.165 approach) or develop transfer function for 1 Hz and 10 Hz design earthquakes, using a single control motion (scaled shape) for each frequency; either envelope the transfer functions or switch from the 1 Hz transfer function to the 10 Hz transfer function at the frequency where the scaled spectra cross.
- Approach 2B: Develop weighted mean transfer functions for 1 Hz and 10 Hz design earthquakes accommodating magnitude distributions; use the 1 Hz transfer function at low frequencies and the 10 Hz transfer function at high frequencies, switching at the frequency where the scaled spectra cross.
- Approach 3: Perform PSHA with rock attenuation relation; deaggregated by M, and R and calculate soil response with appropriate control motions for each M, and R bin.
- Approach 4: UHS computed directly from PSHA using site-specific soil attenuation relations (The Truth?)

Approaches for Developing Soil UHS

Approach 1:

- Uses a single, broadband motion representing the rock UHS to drive the soil column
- Recognized that this may be unconservative
  - May “over-drive” soil column
  - Won’t properly account for nonlinear soil effects expected for a broad range of earthquakes considered in the definition of the rock UHS

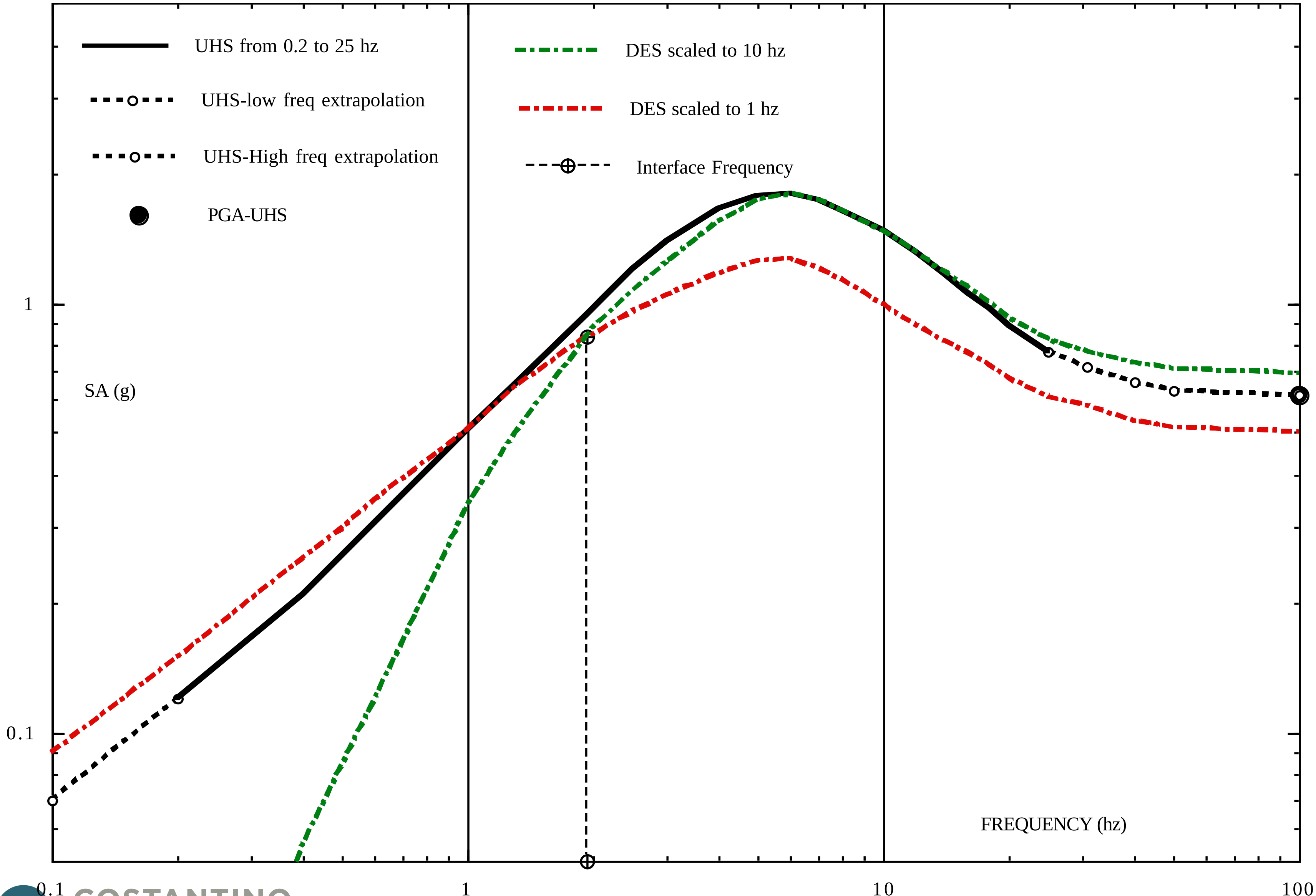

APPROACH 1 PROCEDURE
File: figrpt.crdata1
UHS from 0.2 to 25 hz
UHS-low freq extrapolation
UHS-High freq extrapolation
PGA-UHS
1
0.1
SA (g)
FREQUENCY (hz)
0.1
1
10
100


SPECTRAL
ACCELERATION
(g)
1
0.1
UHS - 0.2 hz to 25 hz
PGA-UHS
UHS - low frequency extrapolation
0.9*UHS
UHS - high frequency extrapolation
1.3*UHS
FREQUENCY (hz)
0.1
1
10
100

Approach 2A

- To minimize overestimating nonlinear effects, the rock input spectra from the PSHA uses controlling motions associated with low frequency (1 Hz) and high frequency (10 Hz) events
- Spectra are generated from the deaggregated hazard data (M and D)
- Resulting soil UHS can be enveloped to obtain overall soil UHS
- Better accounts for effects of magnitude of input spectra on nonlinear soil effects

Approach 2A Rock Inputs



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Approach 2B

- Further refinement of Approach 2A wherein multiple spectra are defined at the low and high frequency
- Better accounts for the variability in input magnitudes and distances defined in the PSHA
- Recognizes that magnitude, for a given rock amplitude, has a strong effect on nonlinear soil response

Approach 4

- Approach based on integration to account for soil amplitude, magnitude, and distance
- Considers full range of soil response effects from every realization of the rock input motions
- Captures full variability associated with all ground motion events considered in the PSHA
- Drawbacks
  - Need applicable soil attenuation equations
  - Empirical attenuation equations use observations at multiple sites, usually on similar soil conditions
    - For our particular site, the attenuation equations might not be applicable

Approach 3

- Simplification of Approach 4
- Discretizes rock motions from the entire hazard over ranges where soil amplification is relatively constant with magnitude
- Does not necessarily converge to Approach 4

LANL Example

- Tasked with performing SSI analysis for a number of critical facilities
- LANL PSHA provides rock and surface UHRS
  - Surface UHRS includes amplification factors accounting for topography as well as differences between Methods 2/3
- Need to estimate spectra at multiple depths in a manner consistent with the development of the PSHA motions

LANL Example (cont.)

- Iterated soil profiles retrieved from PSHA
  - Two base case profiles considered
  - Include nonlinear soil response from Approach 3
- 60 realizations for each base case developed
- Convolve rock UHRS and compute mean S_a at surface
- To account for Method 3 effects, compute $Sa_{UHRS}/Sa_{convolve}$ at surface
- Ratio used to scale in-layer motions to incorporate “Method 3 effects”

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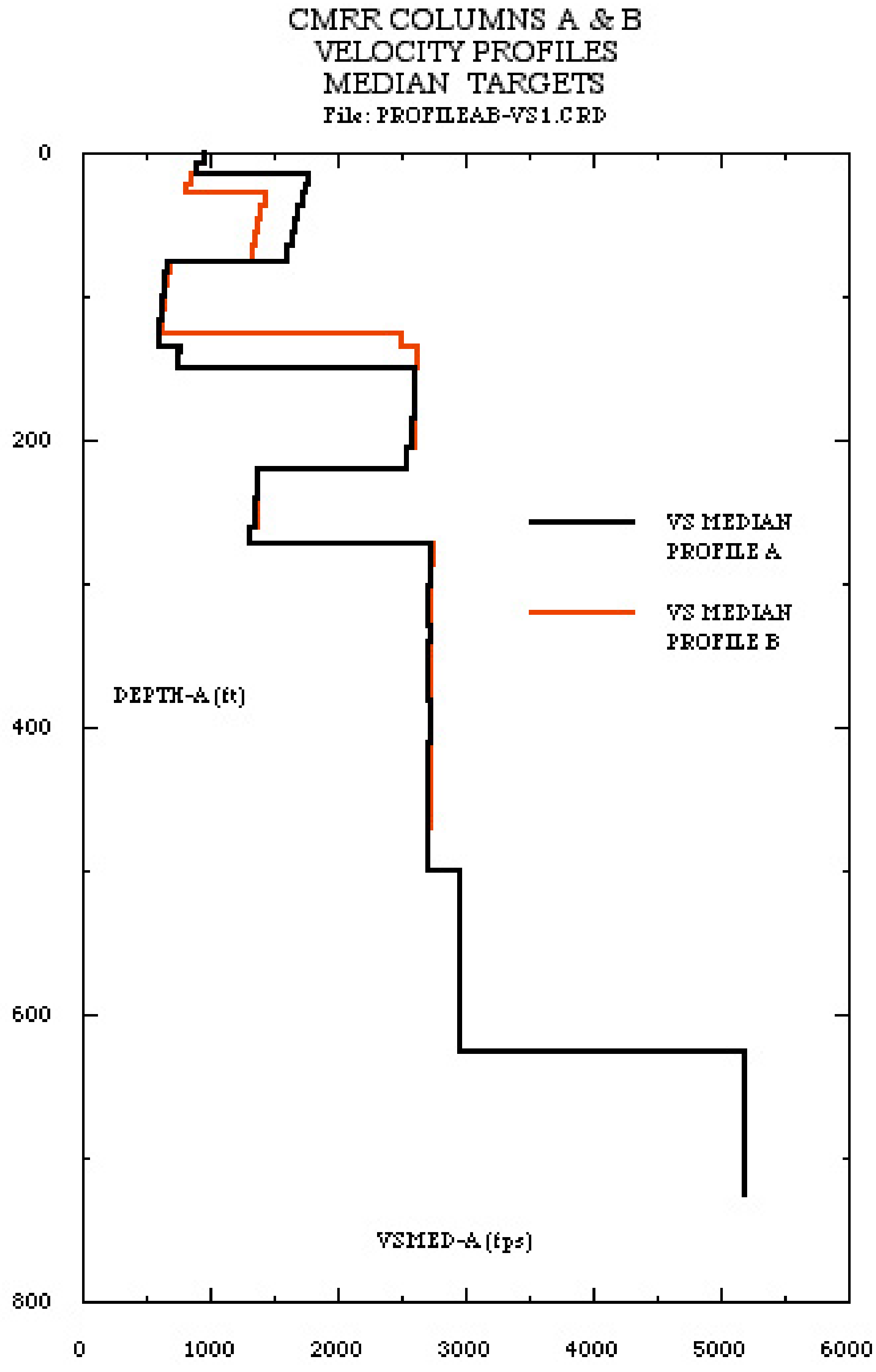
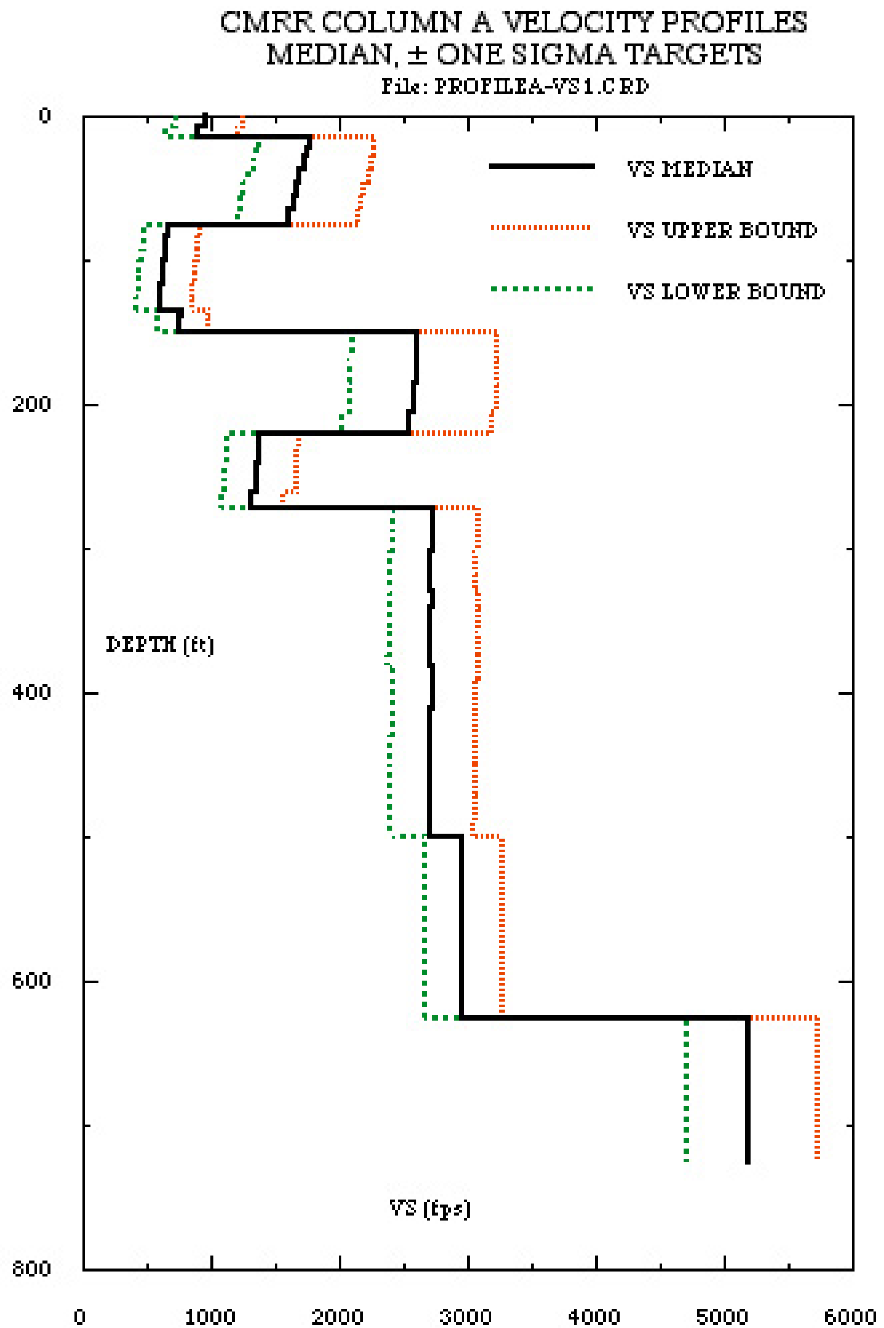
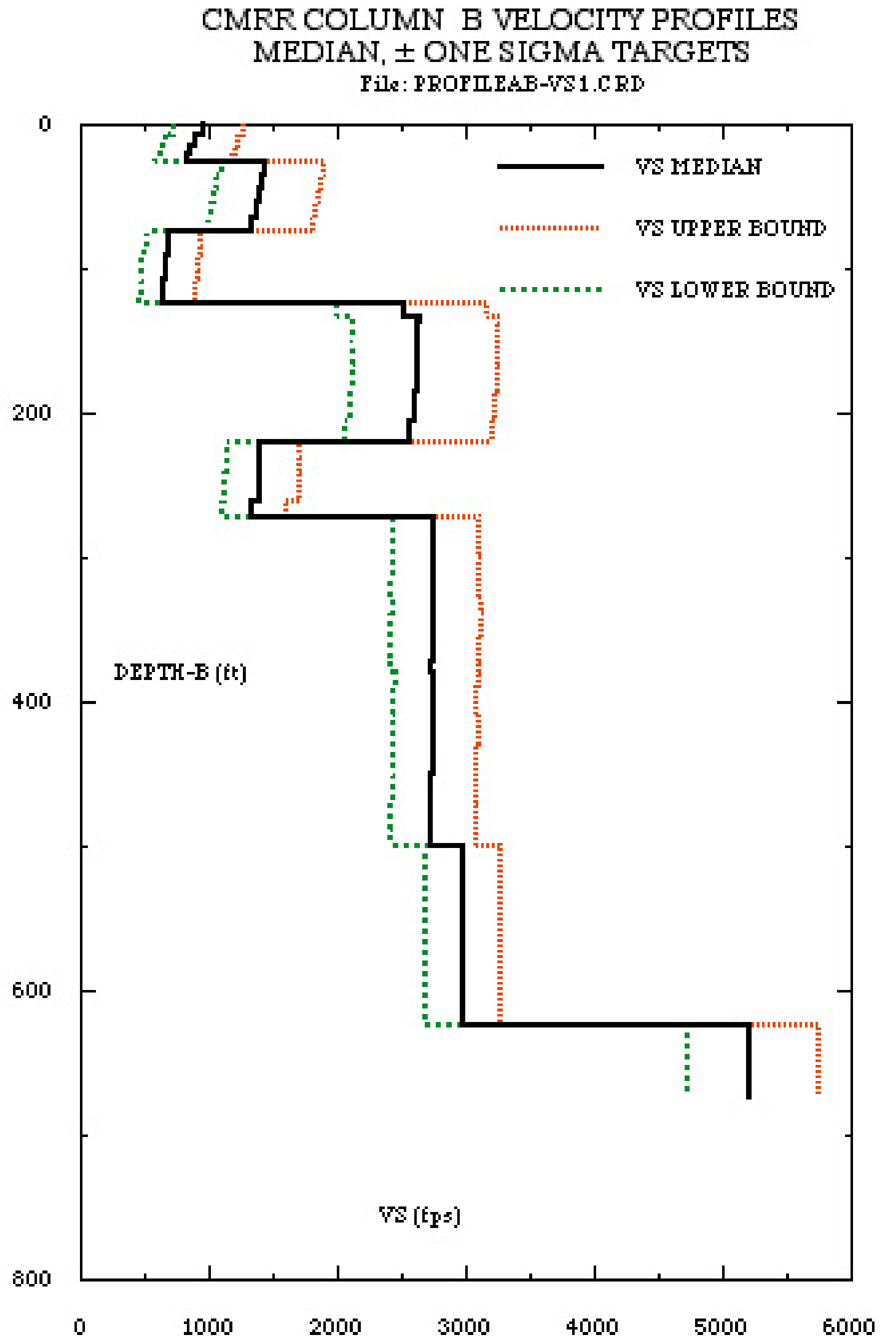

CMRR COLUMNS A & B
VELOCITY PROFILES
MEDIAN TARGETS
File: PROFILEAB-VS1.GRD
0
200
400
600
800
DEPTH-A (ft)
VS MEDIAN
PROFILE A
VS MEDIAN
PROFILE B
VSMED-A (fps)
0
1000
2000
3000
4000
5000
6000



CMRR COLUMN A VELOCITY PROFILES
MEDIAN, ± ONE SIGMA TARGETS
File: PROFILEA-VS1.CRD
VS MEDIAN
VS UPPER BOUND
VS LOWER BOUND
DEPTH (ft)
VS (fps)
0
200
400
600
800
0
1000
2000
3000
4000
5000
6000



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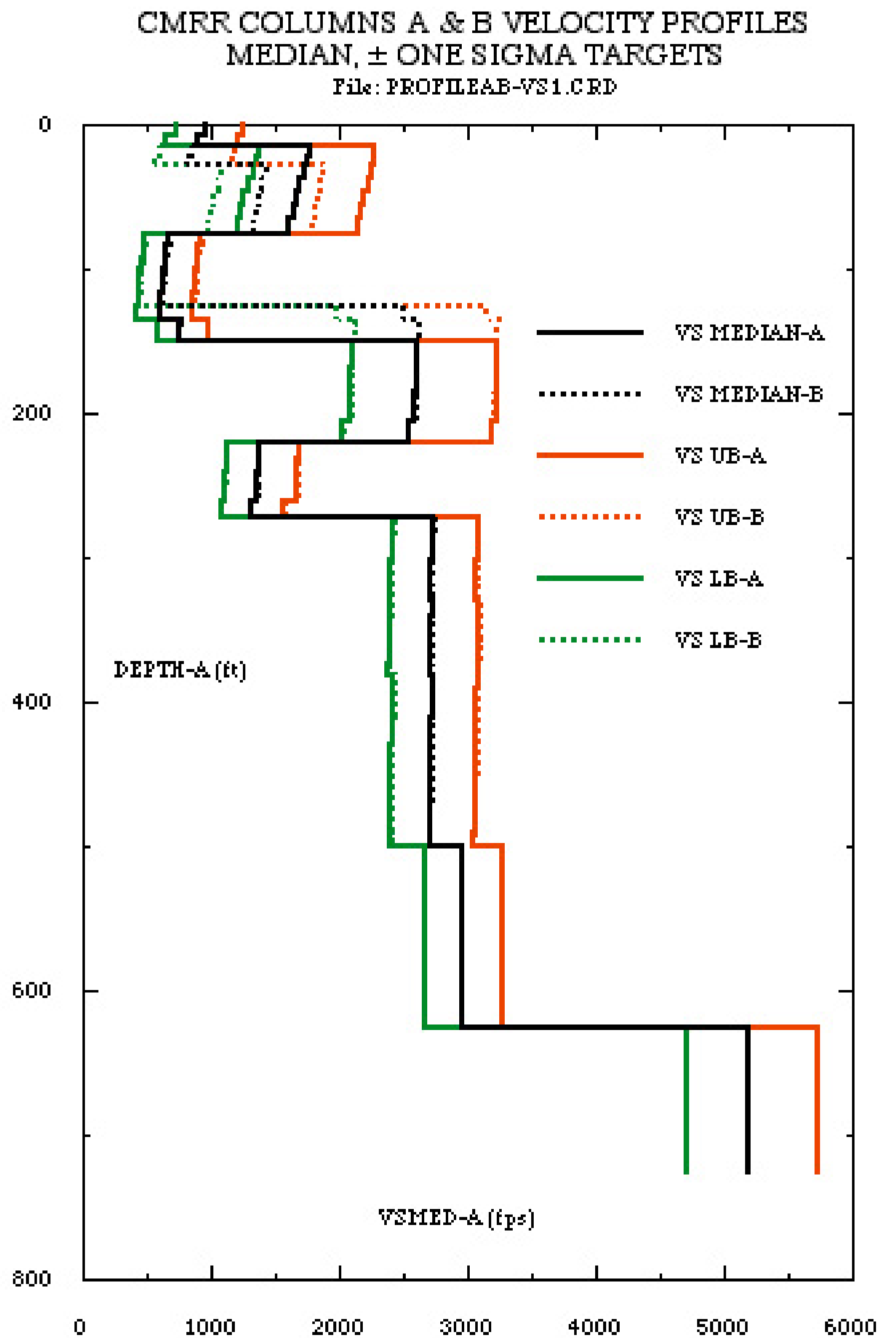

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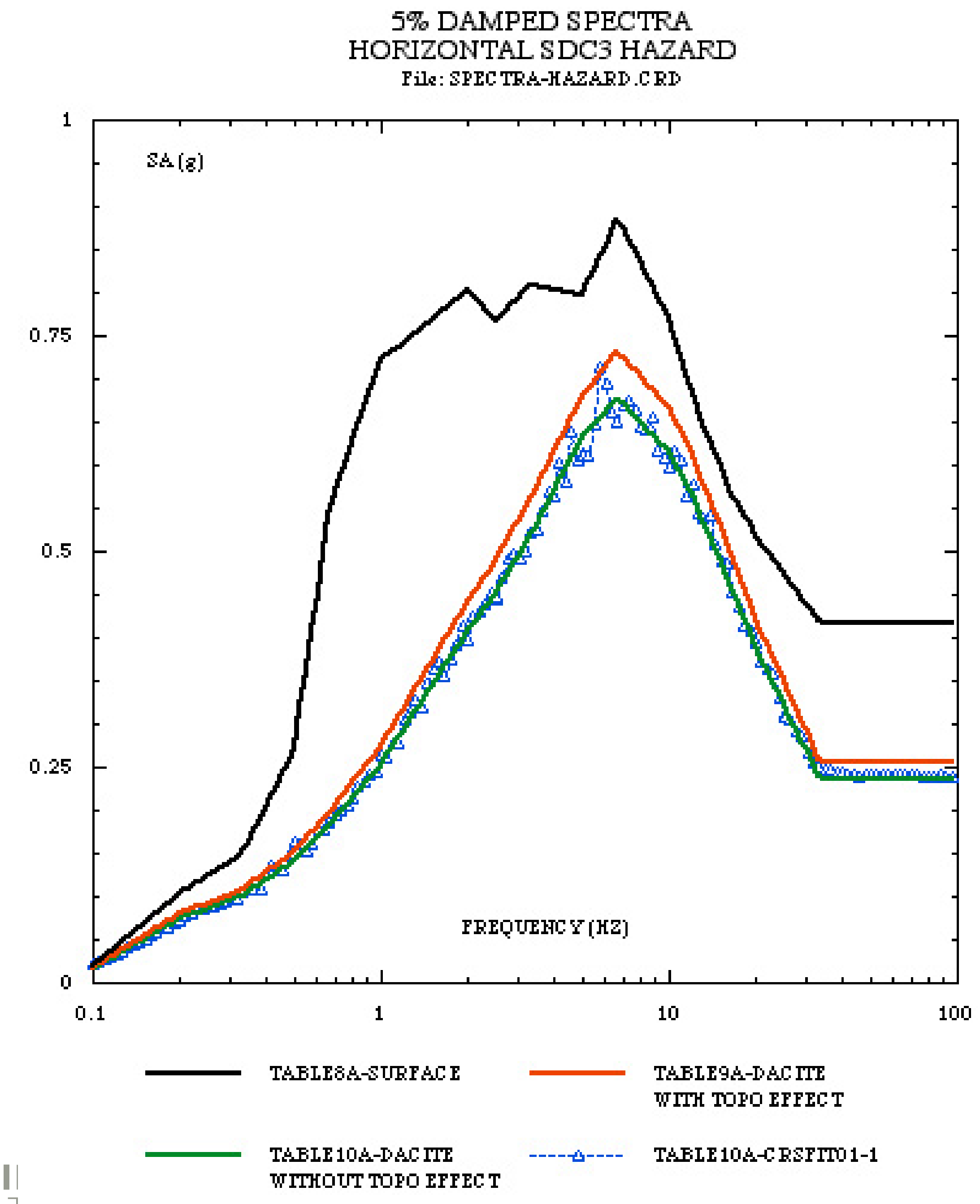

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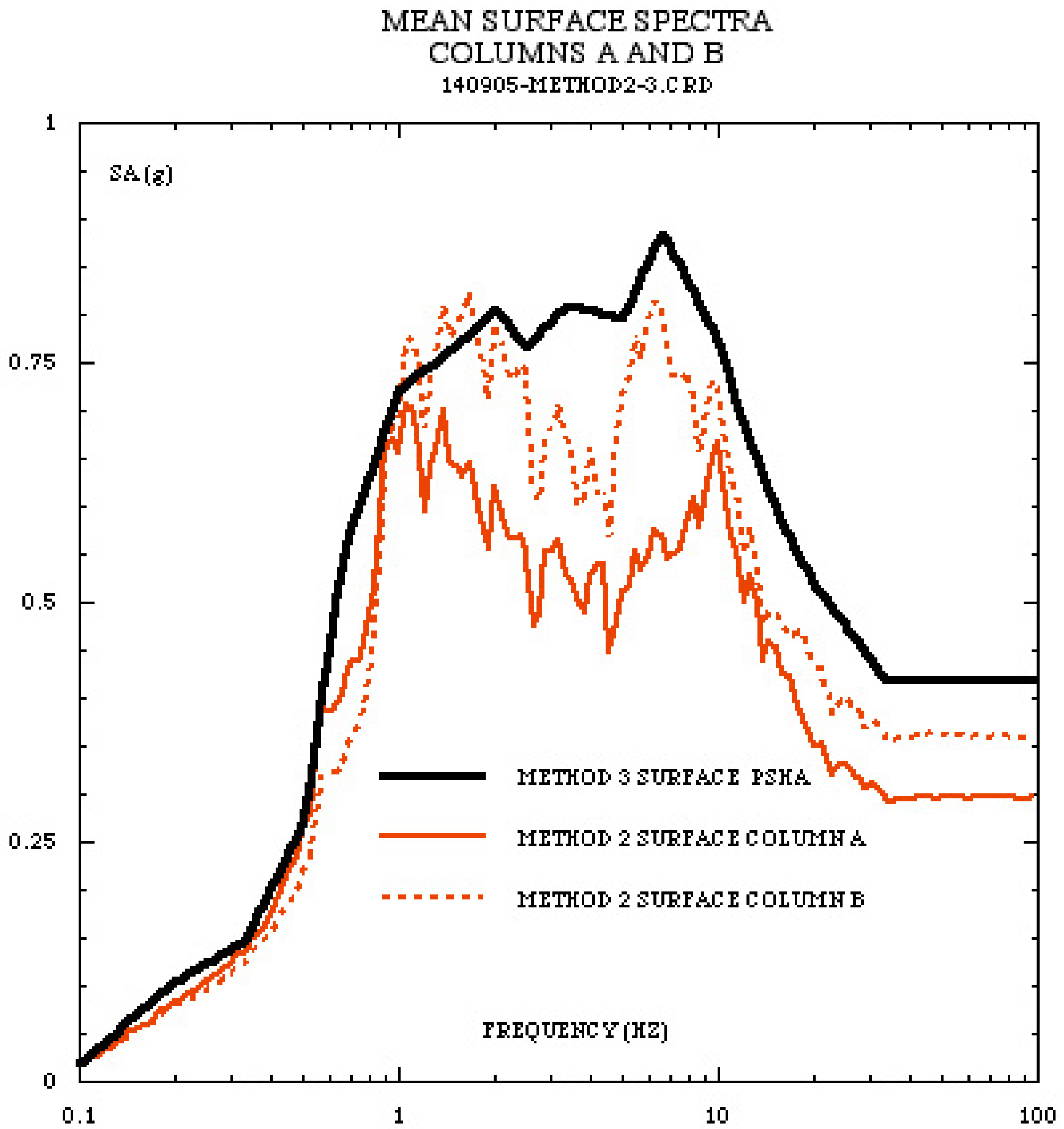
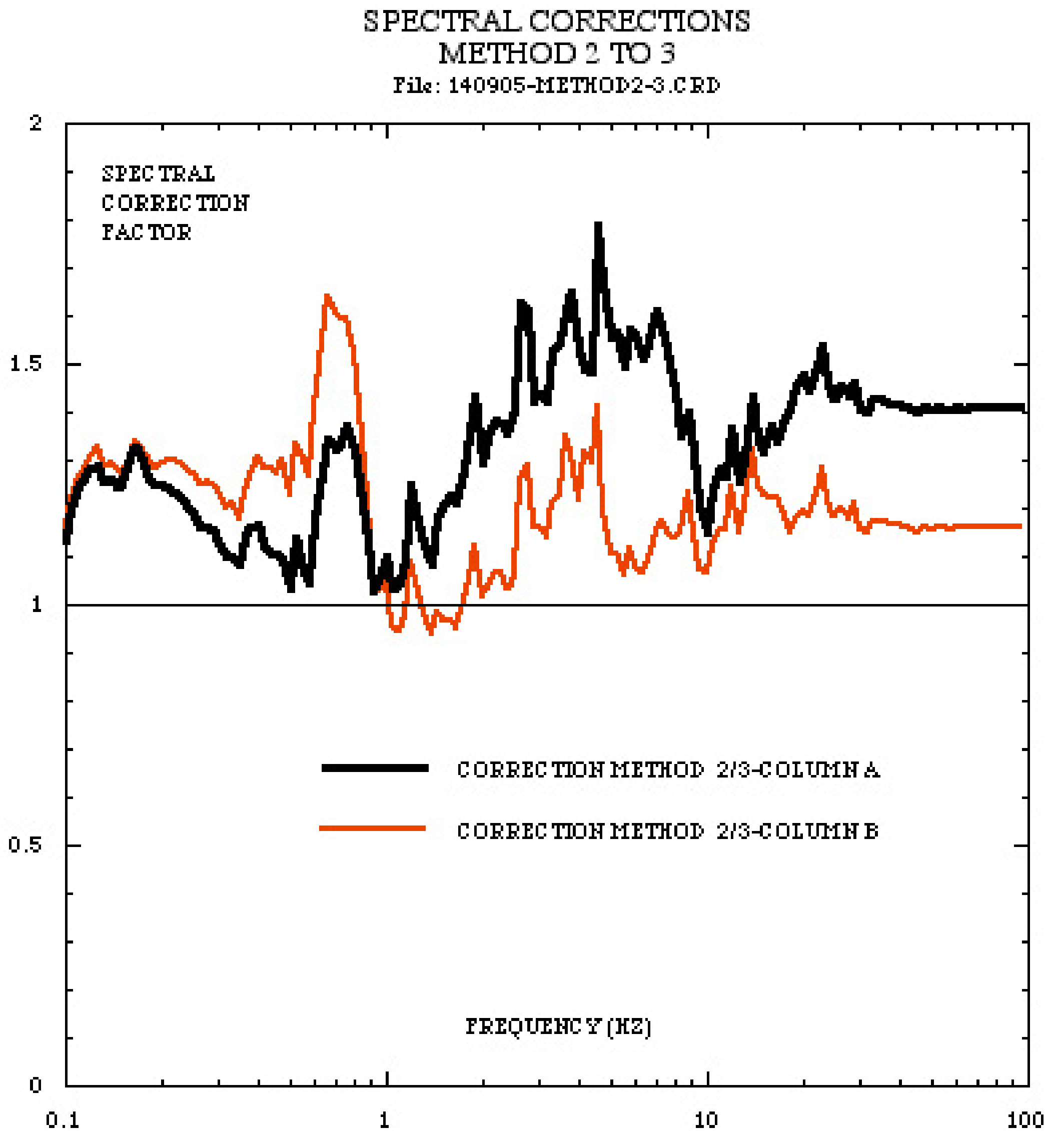


MEAN SURFACE SPECTRA
COLUMNS A AND B
140905-METHOD2-3.CRD
SA (g)
1
0.75
0.5
0.25
0
0.1
1
10
100
METHOD 3 SURFACE PSHA
METHOD 2 SURFACE COLUMN A
METHOD 2 SURFACE COLUMN B
FREQUENCY (HZ)



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Conclusions

- ASCE Standards 4/43 emphasizes the use of Approach 3 in determining soil PSHA
- Approach 3 aims to maintain better consistency with rock hazard defined in PSHA than other approaches
- Requires many more site convolutions than Approach 2
- Differences between Approach 2/3 can be significant and must be evaluated
- Sensitivity of soil PSHA to important details of computations of Soil Amplification Functions not easily defined